17th International Conference on Industrial Engineering and Industrial Management
XXVII Congreso de Ingeniería de Organización
Barcelona, Spain, July 6-7, 2023

Industrial Energy Cluster Optimization using Flexibility Aggregation

Caprara A[1], González-Font-de-Rubinat P[1], Ranaboldo M[1], Bullich-Massagué E[1], Aragüés-Peñalba M[1], Cimmino D[2]

Abstract Individual industries can reduce their energy related costs by stipulating collaborative arrangements in the form of industrial energy communities. This paper analyses a case study of two manufacturing factories constituting an industrial energy community, presenting an approach to minimize grid electricity purchase through the aggregation of their flexibilities. The economic impact of deviating from the baseline production schedule is addressed, taking into account the additional costs of the flexibility offers. The problem is formulated as a mixed-integer linear optimization model, considering the effects of a solar PV power plant and electricity purchase on the day-ahead market. The results of the study show that the proposed approach can significantly reduce the costs of electricity purchase for the factories while maintaining the same level of production, promoting RES penetration and energy security of the cluster.

Keywords: Industrial energy communities; flexibility aggregation; linear optimization; electricity cost minimization.

1 Introduction

In the last decade, power systems all over the world have faced a considerable increase in Renewable Energy Sources (RES) penetration, leading to reduction of CO_2 emissions but also causing system instability due to their intermittent production.

Adriano Caprara (✉e-mail: adriano.caprara@upc.edu)

[1] Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA-UPC), Universitat Politècnica de Catalunya ETS d'Enginyeria Industrial de Barcelona, C. Avinguda Diagonal, 647, 08028 Barcelona, Spain.

[2] Evolvere SpA Società Benefit, 20124 Milano.

Demand-side flexibility, or Demand Response (DR), offers an alternative to system operators to ensure grid stability without involving RES curtailment. Nevertheless, DR is not easily accessible to small and residential consumers due to technical and regulatory barriers which obstruct the participation in flexibility markets. Industries, on the other hand, as large consumers, have a valuable and cost-effective potential in DR (Gils, 2014).

Further facilitating the removal of these barriers, aggregators have gained importance in enabling market access to DR providers. They allow the gathering of distinct agents such as consumers, producers or prosumers, in a single entity that can participate in both wholesale and retail power markets and sell services to system operators (Burger et al., 2017). DR aggregators, are aggregators that also market demand-side flexibility on the spot market and balancing power markets (Stede et al., 2020).

In this study, the focus is put on industries aggregated in a so-called industrial energy cluster. The cluster architecture can improve the industries' energy performance and increase their economic revenue. The multiple consumers under the cluster umbrella share risks and resources, owning power generation free for the cluster to exploit. In this way the figure of the industrial energy cluster has several purposes. First, it acts as a retailer and DR aggregator, buying and selling energy for the cluster and allowing the aggregated industries to reach the minimum bid size to participate in flexibility markets. In addition, the industrial cluster prioritizes self-consumption, thus reducing greenhouse gas emissions and increasing economic savings.

This paper is structured as follows. Section II describes the methodology of the optimization problem, explaining how the industrial energy community is formulated. Section III displays a case-study of an industrial energy community composed by three different factories. Finally, in section IV, the results are presented.

2 Methodology

This section focuses on how the proposed optimization model for the industrial energy community is formulated to minimize the energy related costs of the cluster. The system, represented graphically in **Fig. 1**, is composed by *n* factories, each of which needs to have its energy demand satisfied. Solar PV is available and common to the cluster, as well as connection to the grid. In the proposed industrial energy community, factories can choose between *m* flexibility profiles, each corresponding to distinct production schedules and consequent energy consumption. These profiles are defined for the 24 hours of the day-ahead according to the internal constraints of the individual factories. To each 24-hour profile is associated an additional cost, representing the extra cost that the factories incur upon by deviating from their normal operation profile, denominated baseline profile.

To satisfy the aggregated consumption of the cluster, energy can be provided either by the grid at the retail price or supplied by the PV power plants. In the case of PV surplus, it is assumed that it is possible for the factories to sell it back to the grid. Thus, the goal of the optimization problem is to identify the combination of offers and local energy production that minimizes the costs.

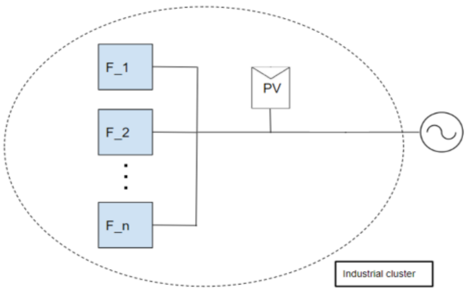

Fig. 1 Schematic representation of a generic industrial energy community composed by *n* factories, with solar PV generation, and connection to the grid.

The choice of the flexibility profiles is formalized considering the following indexes:

- $t = 1, \ldots, T$ as the index over hourly time intervals;
- $i = 1, \ldots, n$ as the index over the different factories;
- $j = 1, \ldots, m$ as the index over the possible profiles of each factory, assuming that they all offer m options.

Given these indexes, we can define the power consumption of factory i, choosing the profile j at time step t as $P_{profile,ijt}$. Then, the binary decision variable x_{ij} is defined to determine which flexibility profile should be selected from each factory. As only one profile can be chosen between the possible production schedules, it is subject to the following constraint:

$$\sum_{j=1}^{m} x_{ij} = 1 \;\; \forall\, i \in \{1, \ldots, n\} \tag{2.1}$$

The total energy consumption of the cluster's factories $P_{cons,t}$ for one time interval t can be expressed as:

$$P_{cons,t} = \sum_{i=1}^{n} \sum_{j=1}^{m} P_{profile,ijt} \cdot x_{ij} \;\; \forall\, t \in \{1, \ldots, T\} \tag{2.2}$$

Similarly, when there is PV production surplus for a given profile, we can express the power sold to the grid at each time interval t as:

$$P_{exp,t} = \sum_{i=1}^{n} \sum_{j=1}^{m} P_{surplus,ijt} \cdot x_{ij} \;\; \forall\, t \in \{1, \ldots, T\} \tag{2.3}$$

Where $P_{surplus,ijt}$ is the surplus power for a given time interval t associated to profile j of factory i.

The costs associated to the power exchanges of the cluster over the whole period can thus be computed as:

$$TC_{power} = \sum_{t=1}^{T} \left(P_{cons,t} \cdot E_{buy,t} - P_{exp,t} \cdot E_{sell,t} \right) \tag{2.4}$$

With $E_{buy,t}$ being the price of the electricity purchased from the grid and $E_{sell,t}$ the price at which it can be sold. Furthermore, the additional cost of changing the profile $C_{profile,ij}$, multiplied by the binary decision variable, is:

$$TC_{profile} = \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot C_{profile,ij} \tag{2.5}$$

Lastly, the cost contribution of emissions is formulated as:

$$TC_{CO2} = \sum_{t=1}^{T} (P_{cons,t} - P_{exp,t}) \cdot C_{CO2} \cdot E_{CO2} \tag{2.6}$$

With C_{CO2} being the CO_2 generation associated to the electricity measured in $kgCO_2/kWh$ and E_{CO2} the cost associated to CO_2 emissions in €/$kgCO_2$. Then, the objective function to minimize the costs of the cluster is defined as:

$$\min(TC_{cluster}) = TC_{power} + TC_{profile} + TC_{CO2} \tag{2.7}$$

Finally, the problem is formulated using Pyomo, an open-source Python-based optimization modeling language, using the GNU Linear Programming Kit (GLPK) solver to minimize the objective function.

3 Case study

The case study is based on two factories engaged in the manufacture of rubber extruded sealing systems. The manufacturing lines are constituted of different processes. Carrier profiling and rubber profile extrusion are common to all the products, while finishing processes, such as vulcanizing or coating, among others, vary according to the product. Additionally, the finishing technologies differ in time and power consumption. This enables industries to generate different production plans with their respective consumption profiles, or to put it differently, to create flexibility profiles. In **Fig. 2**, the different possibilities are shown graphically. Stemming from a real use case, the presented data is created synthetically, to allow the development of the flexibility aggregation framework and optimization model.

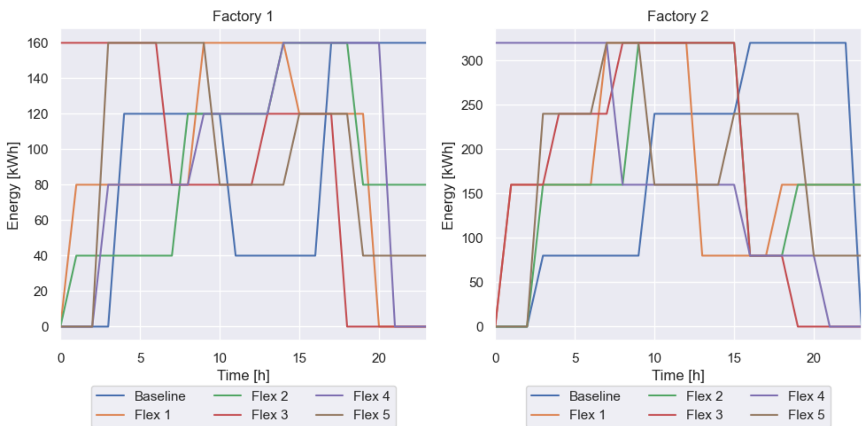

Fig. 2 Energy consumption of the possible production schedules of each factory.

For the sample 24 hours taken into considerations, the additional costs of the proposed flexibility offers are shown in **Table 1**.

Table 1 Additional costs of each 24 h flexibility profile compared to the baseline production schedule costs

	Base [€]	Flex 1 [€]	Flex 2 [€]	Flex 3 [€]	Flex 4 [€]	Flex 5 [€]
Factory 1	0	3	56	7	64	102
Factory 2	0	12	8	2	15	20

Additionally, the electricity prices for the chosen day were taken for a sample day from the Spanish day-ahead market. The values used are displayed in **Fig. 3** below. It is assumed that the price of selling PV surplus to the grid is half of the purchase price.

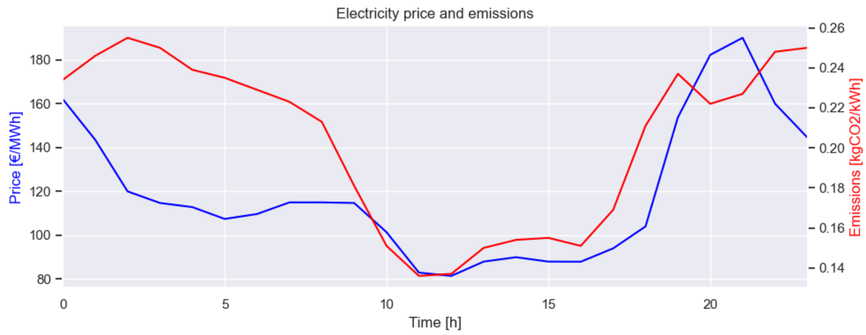

Fig. 3 Day-ahead market electricity price and CO2 emissions associated to the electricity production for the chosen 24 hours sample.

The cost of the CO_2 emissions, then, is estimated assuming a coefficient of 0.07016 €/kgCO_2, according to carbon credits price for October 2022 (SENDECO2, 2023).

4 Results

Solving the model for the chosen sample day, the results of clustered and normal operation are compared. **Table 2** summarizes key metrics to evaluate the improvements brought by the cluster operation. A decrease of 7.6% in the net energy purchased from the grid can be appreciated, and a corresponding reduction of the CO_2 emissions by 6.8%. Overall, the total costs of the two factories diminish by 10.7% by activating flexibility under cluster operation regime. Using a device with an Intel(R) Core(TM) i7-10510U CPU @ 1.80GHz processor with a base clock speed of

2.30GHz and 16 GB of RAM, the problem is solved with low computational costs and 1.21 s of recorded elapsed time

Table 2 Comparison of individual consumption choosing baseline profiles compared to the aggregated flexibility selected by the optimization model.

Metrics	Individual Operation	Cluster Operation
Chosen Profiles	"Baseline", "Baseline"	"Flex 1", "Flex 3"
Net energy consumed [kWh]	5003	4618
CO_2 Emissions [kgCO_2eq]	981	914
Total Costs	625	558

5 Conclusions

In conclusion, the cost optimization methodology developed to minimize grid electricity purchase costs successfully allows to increase the effectiveness of DR strategies within industrial customers. A significant reduction in energy imports and emissions are recorded, confirming the benefits for both companies and the environment. Finally, measuring the associated costs of the two scenarios, savings of up to 10.7% are identified, confirming the validity of the strategy.

Acknowledgements

This work has been supported by the FLEX4FACT project, funded by the European Union under the Horizon Europe research and innovation programme, under the grant agreement number 101058657. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them. Eduard Bullich-Massagué is lecturer of the Serra Húnter programme.

6 References

Burger, S., Chaves-Ávila, J. P., Batlle, C., & Pérez-Arriaga, I. J. (2017). A review of the value of aggregators in electricity systems. *Renewable and Sustainable Energy Reviews*, 395-405.

Gils, H. C. (2014). Assessment of the theoretical demand response potential in Europe. *Energy*, 1-18.

SENDECO2. (2023). *https://www.sendeco2.com/it/prezzi-co2*.

Stede, J., Arnold, K., Dufter, C., Holtz, G., von Roon, S., & Richstein, J. C. (2020). The role of aggregators in facilitating industrial demand response: Evidence from Germany. *Energy Policy*.